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Bulk Mineralogy and Geochemistry of Selected Alaskan Chromian Spinel Samples

By William S. Roberts



UNITED STATES DEPARTMENT OF THE INTERIOR



(United States, Bureau of Mines)

Information Circular 9023

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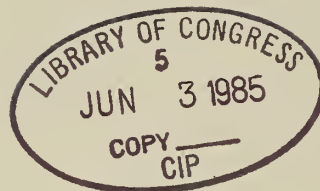
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Å	angstrom	wt %	weight percent
ppm	part per million		

BULK MINERALOGY AND GEOCHEMISTRY OF SELECTED ALASKAN CHROMIAN SPINEL SAMPLES

By William S. Roberts¹

ABSTRACT

As part of the Bureau of Mines critical and strategic minerals program in Alaska, 34 high-purity chromian spinel samples were analyzed for trace and major element geochemistry and mineralogy. The samples were analyzed by X-ray diffraction, X-ray fluorescence, and chemical techniques.

Systematic differences in chemistry are evident when samples collected from the Chugach Mountains and their related extension are compared with chromian spinel samples collected from interior Alaska. Compared with the Chugach samples, the interior Alaska samples have higher average amounts of Al_2O_3 , Fe_2O_3 , TiO_2 , and NiO , have lower average amounts of FeO and Cr_2O_3 , and exhibit greater dispersion in values.

Considerable mineralogical variability of chromian spinel exists between and within individual Alaskan chromite-bearing ultramafic complexes. Of 34 samples analyzed, 25 samples are magnesiochromite, 5 are chromite, 3 are spinel, and 1 is hercynite. As a group the interior Alaska samples have a smaller average unit cell dimension than the Chugach group of samples.

The chemical and mineralogical differences between the two groups of samples can be attributed to different genetic histories and may have implications for locating chromian spinel deposits amenable to standard beneficiating techniques.

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INTRODUCTION

This report summarizes mineralogical and geochemical work done on samples collected during field investigations of Alaskan chromite occurrences. Field work assessing chromite deposits, as part of a critical and strategic minerals program, began in 1981 by the Bureau of Mines Alaska Field Operation Center (AFOC), and several deposits have recently been described (6-7, 11).² Beneficiation studies of chromian spinel samples have been done by the Bureau's Albany Research Center (ALRC) (3-4).

The purpose of this study is to characterize and compare the geochemical determinations for 34 purified chromian spinel samples. The samples, plus 18 other chromian spinel samples, were analyzed by

X-ray diffraction. Chromite mineralogy is sufficiently complex to require a combination of X-ray diffraction, X-ray fluorescence, and chemical analyses for characterization.

Previous studies have focused on the description of chromian spinel occurrences and standard beneficiation tests of bulk samples. Mineralogical determinations have generally been restricted to the identification of gangue and trace minerals associated with chromian spinel. This report provides information on the mineralogy of Alaskan chromian spinel samples and reports trace and major oxide chemical signatures of samples collected statewide.

ACKNOWLEDGMENTS

K. Broadhead, metallurgical engineer, Reno Research Center, provided the FeO determinations, and D. Dahlin,

metallurgist, Albany Research Center, provided splits of chromian spinel samples.

SAMPLES

Fifty-two samples were collected by Bureau personnel. The samples represent splits taken from grab or bulk samples that were high-graded in the field for mineralogical and beneficiation tests. The results of this study represent reconnaissance-type information since a few samples from each occurrence do not constitute a thorough characterization for any single deposit, area, or region.

The samples were obtained from widely scattered ultramafic occurrences across

the State; however, all chromian spinel occurrences in Alaska are not represented in this report (fig. 1). For comparative purposes the samples are lumped into two logical groups that are based on geographic location or extension of geographic or geologic features. The two groups include the interior Alaska and Chugach groups. General localities and grouping of the samples are indicated in appendix C.

PROCEDURES

The procedures used for this study are not standard concentration techniques. High-purity chromian spinel samples are required for mineralogical characterization using molecular proportion plots, so modified laboratory techniques were used.

Two different sources for samples resulted in slight variations in the concentration procedures. Samples archived at AFOC were prepared in the manner outlined in figure 2. Samples received from ALRC were table concentrates of minus 28-plus 65-mesh sized fraction, so crushing and hand picking were not required.

²Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

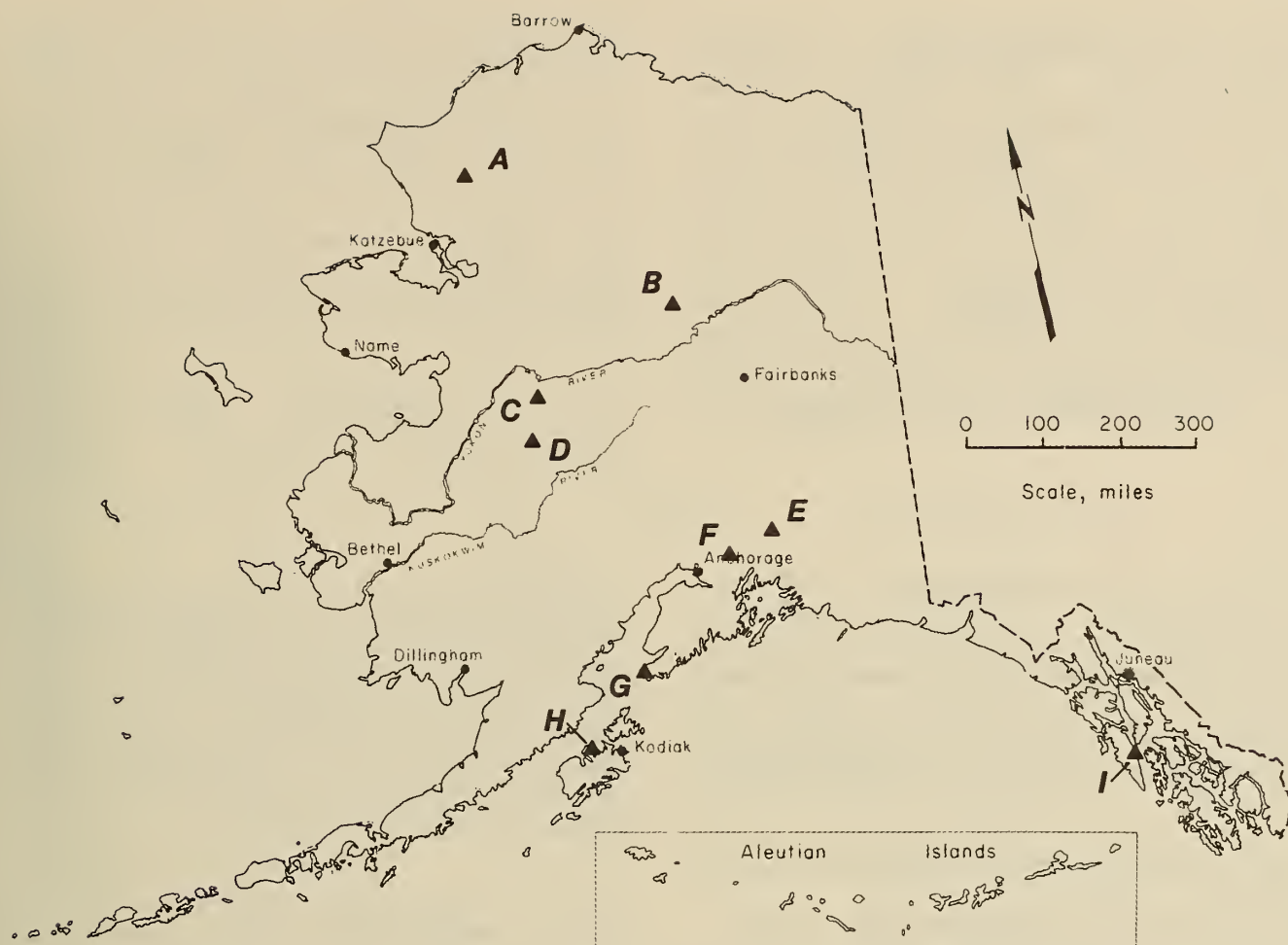


FIGURE 1. - Locations of ultramafic rocks hosting chromian spinel occurrences characterized in this report. A, Avan Hills; B, Caribou Mountain, Kanuti River; C, Yuki River; D, Mount Hurst; E, Tonsina-Bernard, Sheep Hill; F, Wolverine Complex, Eklutna; G, Claim Point, Red Mountain; H, Miners Bay, Grant Lagoon, Halibut Bay; I, Red Bluff Bay.

The samples were run through a laboratory model isodynamic magnetic separator to remove all magnetite, and a hydrofluoric acid (HF) bath effectively removed unwanted silicate minerals. The HF bath altered the magnesium silicates to chondrodite, a relatively low density, fragile fluorohydroxide which could be washed out by agitation and wet screening. There is no evidence the HF bath altered the chemistry or mineralogy of the chromian spinels.

High-purity chromian spinel concentrates free of magnetite and silicates were analyzed by energy-dispersive X-ray

fluorescence spectrometry (XRF), with the exception of FeO, which was analyzed by wet chemical methods. Ferric oxide (Fe_2O_3) was calculated from total Fe.

The analytical precision is less than a few percent relative error, while errors in accuracy may range as high as $\pm 20\%$ in the case of Mg or trace elements because of low counting rates. Comparison of Fe and Cr determinations by ALRC and AFOC during this study generally indicates a relative error in accuracy of $\pm 5\%$ to 10% or less. National Bureau of Standards NBS103A was the primary reference standard used in the XRF determinations.

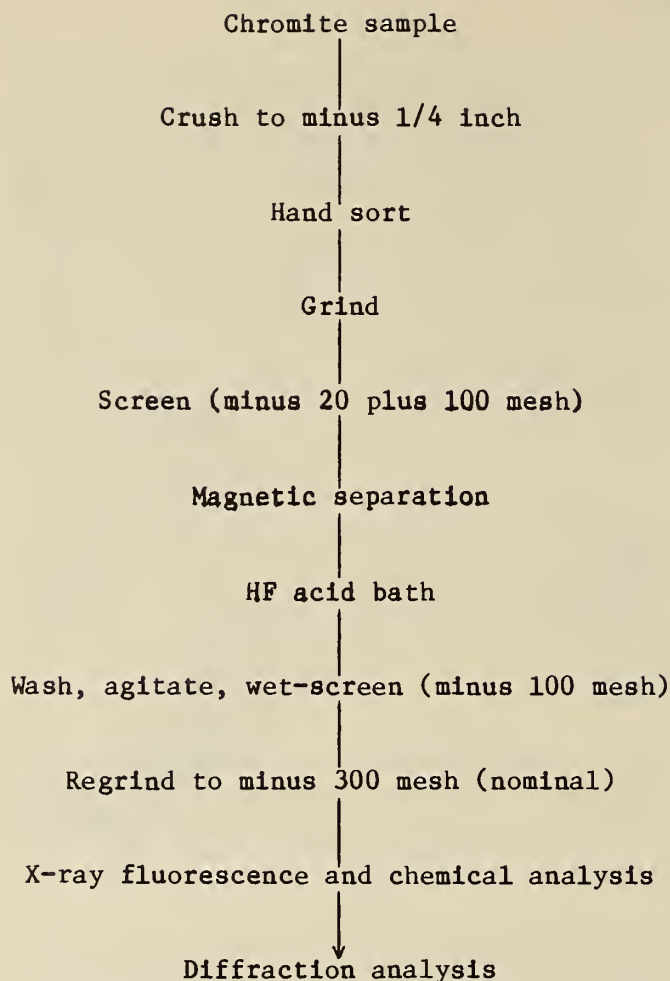


FIGURE 2. - Schematic diagram of sample preparation procedures. Samples received from Albany were concentrated using tabing methods, and splits consisted of minus 28-plus 65-mesh fractions. These samples were treated beginning with the magnetic separator.

After analysis by XRF the samples were analyzed by X-ray diffraction using two modes: a scanning speed of $1/4^\circ$ two-theta per minute from 31° to 37° two-theta, and a scanning speed of 2°

NOMENCLATURE AND MINERALOGY

Mineral nomenclature is adapted from Palache (10) and conforms to terminology used by the Joint Committee Powder Diffraction Society (1). Chromite from podiform and stratiform ultramafics is

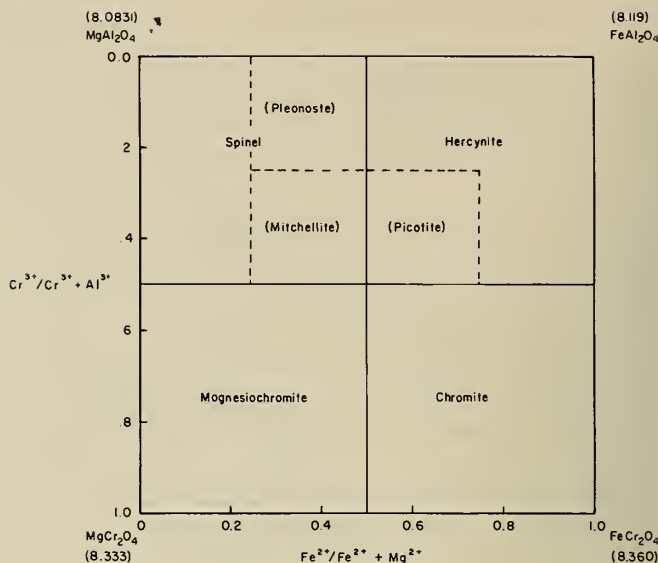


FIGURE 3. - Nomenclature of chromium-bearing spinels based on molecular proportion plot of divalent and trivalent cations. Note: Changes along horizontal axis reflect different proportions of divalent cations (Fe, Mg), and changes on the vertical axis represent different proportions of trivalent cations (Cr, Al). Unit cell dimensions, in angstroms, are indicated in parentheses and are for end member minerals only.

two-theta per minute from 2° to 62° two-theta. Measured precision of d-spacings in the former mode is $\pm 0.0005 \text{ \AA}$. An internal standard (NaCl) was used to standardize the d-spacing measurements using a full-width-half-maximum technique of marking peak centroids.

The (113) d-spacing, the strongest spinel reflection, was used to calculate unit cell dimensions. Since multiple reflections from different crystallographic planes were not used to calculate the unit cell dimensions, the values reported must be considered provisional.

Mineralogically part of the spinel group, which consists of the magnetite, spinel, and chromite series. Spinel-group minerals may be represented by the general formula AB_2X_4 , which may be expressed

as $R^{2+}R^{3+}_2O_4$ (13). Extensive ionic substitution of divalent cations (Fe, Mg, and Ti) and trivalent cations (Cr, Al, Fe, and Mn) makes characterization by X-ray diffraction difficult since crystal lattice dimensions are variably affected by substitution at the octahedral and tetrahedral positions. Although there are natural limits on ionic substitution, characterization is best achieved by combining X-ray diffraction and quantitative chemistry.

Low-titanium chromium-bearing spinels consist of six idealized end members: chromite ($FeCr_2O_4$), magnesiochromite

($MgCr_2O_4$), hercynite ($FeAl_2O_4$), spinel ($MgAl_2O_4$), magnesioferrite ($MgFe_2O_4$), and magnetite (Fe_3O_4) (9). A multicomponent prism described by Haggerty (8) best characterizes chromium spinels, but for this study only the base of the prism is used. Figure 3 outlines, on a molecular proportion plot, the fields represented by four of the end-member minerals listed above. Magnesioferrite and magnetite are not represented on the plot, although there is an appreciable ferrian (Fe^{+3}) component represented by the analyses.

RESULTS

The results of the chromian spinel chemical analyses are presented after a brief discussion of X-ray diffraction results. Diffraction data for 52 samples are listed in appendix A, along with chemical results for 34 samples. Molecular proportions of the principal spinel cations are listed in appendix B, and mineral terms and general localities are tabulated in appendix C.

X-RAY DIFFRACTION

High-resolution X-ray diffraction indicates that average d-spacings of the (113) reflection vary from 2.4835 to 2.5260 Å. These measurements indicate unit cell dimensions of 8.237 to 8.378, respectively. Figure 4 represents a plot of calculated cell dimensions with summary envelopes of the Chugach and interior Alaska groups of samples. There is a clear difference in average cell dimensions, with the Chugach group averaging 8.312 Å and the interior Alaska group averaging 8.279 Å. The disparity in unit cell dimensions is apparently due to a difference in average amounts of Al, Mg, Fe, and Cr.

Eleven samples have multiple (113) reflections ("doublet"), indicating more than one spinel mineral is present. Nine of the 11 samples with doublets are from the Chugach group of samples. Dahlin (3) and Bliss (2) describe zoned chromian spinel minerals, which are the probable cause for the doublets.

X-RAY FLUORESCENCE

Plots comparing molecular proportions of $Fe^{2+}/Fe^{2+} + Mg^{2+}$ and $Cr^{3+}/Cr^{3+} + Al^{3+}$ concentrations are presented in figure 5. The plots define R^{2+} and R^{3+} cation proportions and the mineralogy of the high-purity bulk chromian spinel splits. Fe^{+3} is not represented on the plot even though the chemical analyses indicate an appreciable ferrian component.

Mineral terms for 34 samples are based mainly on molecular proportions. Analysis by X-ray diffraction was used to check purity of the samples and to confirm the presence of a spinel. A total of 25 samples are characterized as magnesiochromite, 5 are chromite, 3 are spinel, and 1 is hercynite.

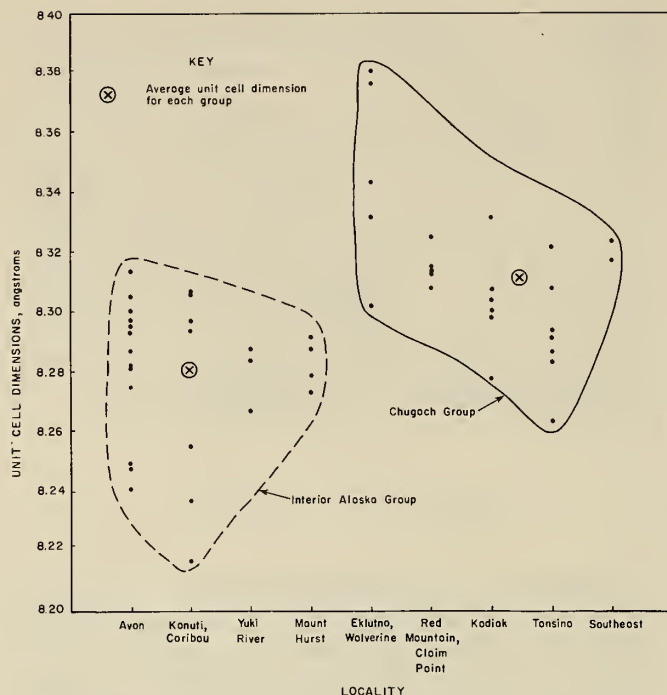


FIGURE 4. - Unit cell dimensions of chromian spinel based on (113) reflection. Note: Envelopes are used to diagrammatically illustrate differences between the interior Alaska and Chugach groups of samples. The range of cell dimensions shows the variation in chromian spinel compositions within a related area or complex.

The concentrations of major oxides in the chromian spinel samples exhibit considerable variability (table 1). This variability exists not only between regions, but between samples taken within the same ultramafic complex. This emphasizes the importance of understanding the chemistry and mineralogy of chromian spinel occurrences since the

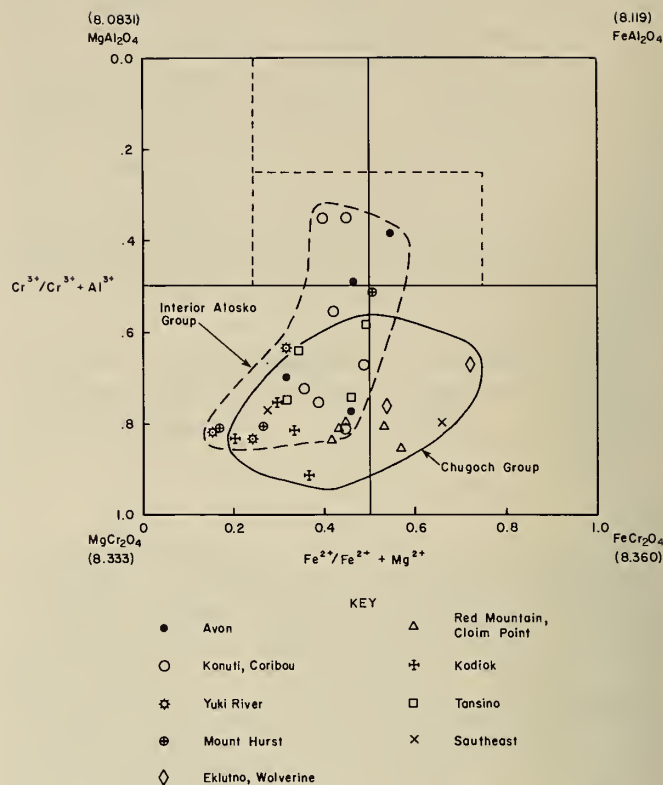


FIGURE 5. - Molecular proportion plot of purified chromian spinel samples. Note: Refer to figure 3 for mineral nomenclature.

beneficiating procedures and market depend heavily on ore chemistry.

Systematic chemical and unit cell differences exist between the Chugach and interior Alaska samples when the groups, rather than specific samples, are compared. Compared with the Chugach group of samples, the interior Alaska group

TABLE 1. - Range of oxide concentrations in chromian spinel samples, weight percent

Oxide ¹	Minimum value	Maximum value	Mean value
MgO.....	4.5	17.7	11.4
Al ₂ O ₃	7.0	26.7	13.9
Cr ₂ O ₃	25.8	59.8	49.5
Fe ₂ O ₃	0	15.6	8.2
FeO.....	4.2	22.0	14.5

¹Oxides based on X-ray fluorescence analyses except FeO which was determined chemically by the Bureau of Mines, Reno Research Center. The Fe₂O₃ values were calculated from total iron.

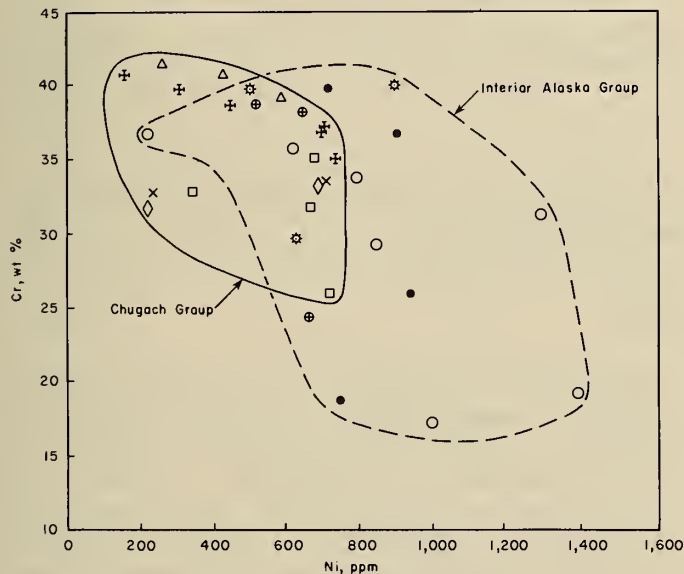
samples have higher average amounts of Al_2O_3 , Fe_2O_3 , TiO_2 , and NiO and exhibit greater dispersion in values (table 2). Figures 6, 7, and 8 graphically summarize the differences between the two groups

when Ni, Zn, and Ti concentrations are compared to Cr content. The significance of the chemical differences between the groups can be attributed to different genetic histories.

TABLE 2. - Statistical comparison of oxides and lattice data for the interior Alaska and Chugach group of samples

Statistical parameter	Interior Alaska group			Chugach group		
	N ¹	Mean wt %	SD, ² wt %	N ¹	Mean wt %	SD, ² wt %
MgO.....	17	11.2	2.1	17	11.5	3.9
Al_2O_3	17	17.4	8.9	17	10.4	3.8
FeO.....	17	12.7	4.3	22	15.8	4.0
Fe_2O_3	17	9.5	4.1	17	6.9	3.5
Cr_2O_3	17	46.4	11.6	17	52.5	6.1
SiO_2	17	0.27	0.19	17	0.27	0.21
P_2O_5	17	0.12	0.04	17	0.11	0.04
TiO_2	17	0.50	0.22	17	0.30	0.15
NiO.....	17	0.10	0.04	17	0.06	0.03
ZnO.....	17	0.11	0.10	17	0.09	0.09
d-spacing.....Å..	27	2.4965	0.0075	27	2.5060	0.0081
Unit cell.....Å..	27	8.279	0.024	27	8.312	0.027

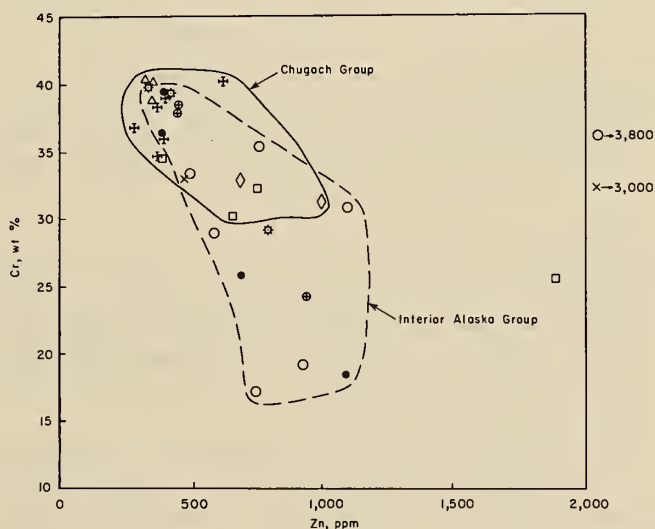
¹N = number of observations. ²SD = standard deviation.



KEY

● Avan	△ Red Mountain, Claim Point
○ Kanuti, Caribou	⊕ Kodiak
⊛ Yuki River	□ Tansina
⊗ Mount Hurst	× Southeast
◇ Eklutna, Wolverine	

FIGURE 6. - Trace Ni versus Cr. Note: Envelopes are used to diagrammatically illustrate differences between the interior Alaska and Chugach groups of samples.



KEY

● Avan	△ Red Mountain, Claim Point
○ Kanuti, Caribou	⊕ Kodiak
⊛ Yuki River	□ Tansina
⊗ Mount Hurst	× Southeast
◇ Eklutna, Wolverine	

FIGURE 7. - Trace Zn versus Cr. Note: Envelopes are used to diagrammatically illustrate differences between the interior Alaska and Chugach groups of samples.

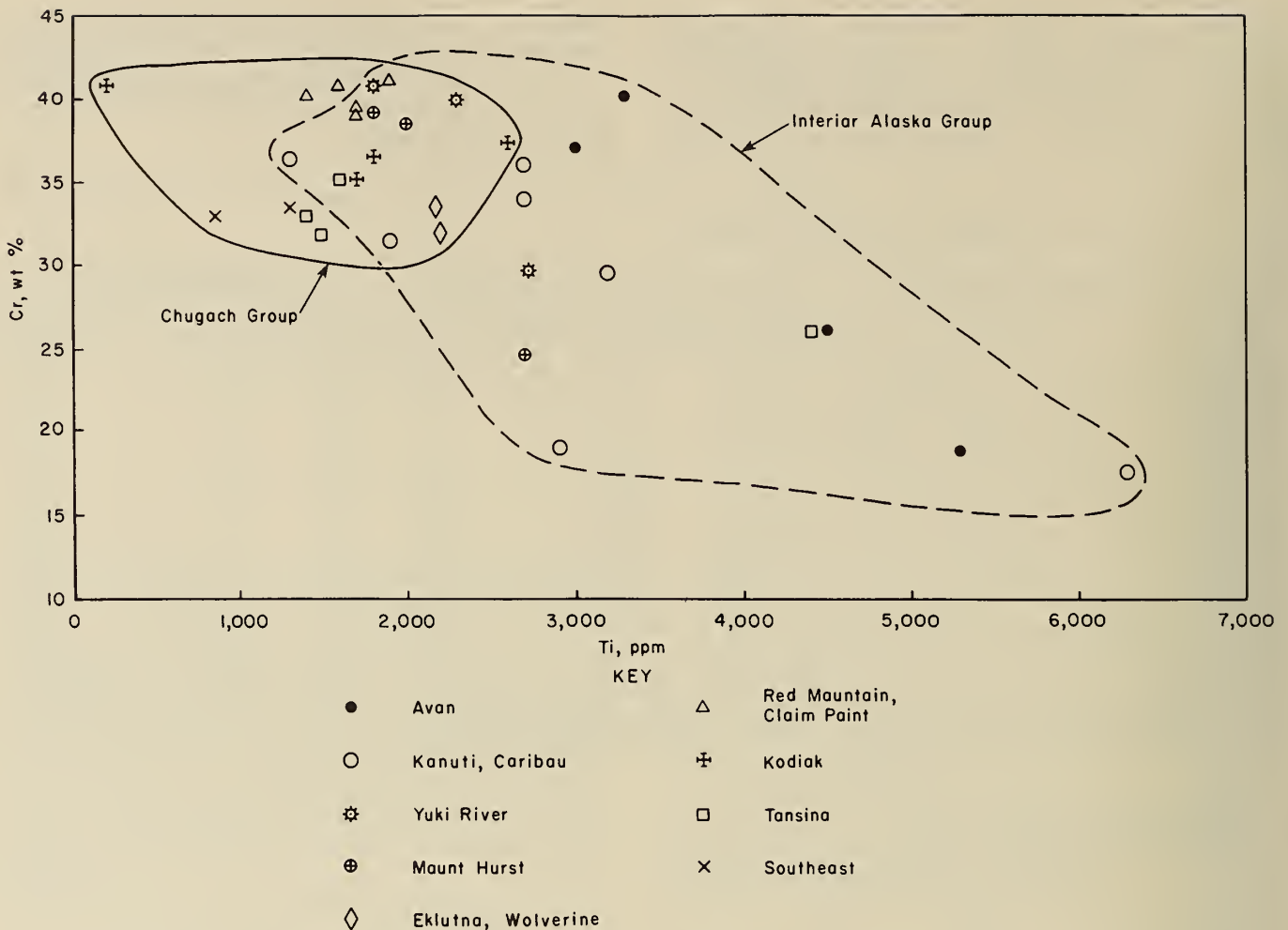


FIGURE 8. - Trace Ti versus Cr. Note: Envelopes are used to diagrammatically illustrate differences between the interior Alaska and Chugach groups of samples.

CONCLUSIONS

The following conclusions are based on X-ray diffraction, X-ray fluorescence, and chemical analyses of 34 high-purity chromian spinel samples:

1. Samples that are grouped by region or geologic extension have systematic chemical differences when average values are compared. The interior Alaska group of samples, when compared to the Chugach group of samples, have higher average amounts of Al_2O_3 , Fe_2O_3 , TiO_2 , and NiO , exhibit greater dispersion in values, have lower average amounts of FeO and Cr_2O_3 , and have similar average MgO concentrations.

2. Considerable mineralogical variability exists between and within individual Alaskan chromian spinel-bearing

ultramafic complexes. Of 34 chromian spinel samples analyzed, 25 consist of ferroan or aluminian magnesiochromite, 5 are aluminian or magnesian chromite, 3 are chromian spinel, and 1 is chromian hercynite. The Chugach sample group has a larger average unit cell dimension when compared to the interior Alaska group of samples and has a higher incidence of doublet (113) diffraction reflections, indicating the presence of more than one spinel phase.

3. The chemical and mineralogical differences between the groups may be a significant factor in the location of chromian spinel deposits amenable to standard beneficiating techniques.

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APPENDIX A. --ANALYTICAL RESULTS¹

Sample No.....	1	2	3	4	5	6	7	8	9	10
Analysis, wt %:										
MgO.....	NA	9.8	9.3	NA	NA	NA	NA	8.1	NA	NA
Al ₂ O ₃	NA	11.5	26.7	NA	NA	NA	NA	29.8	NA	NA
FeO.....	NA	15.0	15.0	NA	NA	NA	NA	18.0	NA	NA
Fe ₂ O ₃	NA	2.5	7.5	NA	NA	NA	NA	14.3	NA	NA
Cr ₂ O ₃	NA	58.7	38.3	NA	NA	NA	NA	27.4	NA	NA
SiO ₂	NA	0.06	0.63	NA	NA	NA	NA	0.24	NA	NA
P ₂ O ₅	NA	0.15	0.08	NA	NA	NA	NA	0.10	NA	NA
TiO ₂	NA	0.56	0.76	NA	NA	NA	NA	0.89	NA	NA
NiO.....	NA	0.09	0.12	NA	NA	NA	NA	0.09	NA	NA
ZnO.....	NA	0.05	0.08	NA	NA	NA	NA	0.14	NA	NA
d-spacing...Å..	2.5010	2.5015	2.4845	2.4970	2.5025	2.4970	2.4985	2.4870	2.4875	2.4950
Unit cell...Å..	8.295	8.297	8.240	8.282	8.300	8.282	8.287	8.248	8.250	8.275
Sample No.....	11	12	13	14	15	16	17	18	19	20
Analysis, wt %:										
MgO.....	NA	NA	11.0	12.3	11.3	11.4	11.7	9.9	8.6	12.9
Al ₂ O ₃	NA	NA	15.2	11.7	22.9	31.9	8.5	34.6	15.0	12.9
FeO.....	NA	NA	9.3	14.0	15.0	17.0	17.0	12.0	15.0	13.0
Fe ₂ O ₃	NA	NA	7.7	6.3	5.6	13.4	3.5	11.1	14.1	9.2
Cr ₂ O ₃	NA	NA	54.2	52.7	43.1	25.8	53.9	28.2	46.1	49.8
SiO ₂	NA	NA	0.16	0.12	0.11	0.30	0.19	0.12	0.17	0.09
P ₂ O ₅	NA	NA	0.12	0.19	0.07	0.09	0.07	0.08	0.19	0.20
TiO ₂	NA	NA	0.50	0.45	0.53	1.05	0.22	0.48	0.32	0.45
NiO.....	NA	NA	0.12	0.08	0.11	0.13	0.03	0.18	0.17	0.10
ZnO.....	NA	NA	0.05	0.10	0.07	0.09	0.47	0.112	0.14	0.06
d-spacing...Å..	2.5065	2.5005	2.5040	2.5005	2.4890	2.4835	2.5045	2.4775	2.5045	2.5015
Unit cell...Å..	8.313	8.293	8.305	8.293	8.255	8.237	8.306	8.217	8.306	8.296
Sample No.....	21	22	23	24	25	26	27	28	29	30
Analysis, wt %:										
MgO.....	11.7	11.6	16.4	NA	13.4	8.4	12.0	13.5	NA	NA
Al ₂ O ₃	8.5	7.8	16.7	NA	10.1	22.4	9.8	3.6	NA	NA
FeO.....	4.2	6.8	14.0	NA	9.1	16.0	4.6	14.0	20.0	19.0
Fe ₂ O ₃	15.6	9.6	7.4	NA	6.5	15.2	12.3	3.6	NA	NA
Cr ₂ O ₃	58.2	59.5	43.6	NA	57.4	36.0	56.4	59.8	NA	NA
SiO ₂	0.23	0.39	0.22	NA	0.53	0.64	0.45	0.24	NA	NA
P ₂ O ₅	0.17	0.10	0.12	NA	0.11	0.09	0.09	0.14	NA	NA
TiO ₂	0.39	0.30	0.44	NA	0.31	0.44	0.32	0.03	NA	NA
NiO.....	0.07	0.12	0.08	NA	0.07	0.08	0.08	0.02	NA	NA
ZnO.....	0.05	0.04	0.10	NA	0.06	0.12	0.06	0.08	NA	NA
d-spacing...Å..	2.4925	2.4975	2.4990	2.5000	2.4990	2.4945	2.4960	2.5120	2.4955	2.4970
Unit cell...Å..	8.267	8.283	8.288	8.291	8.288	8.273	8.278	8.331	8.277	8.282

See explanatory notes at end of table.

Sample No.....	31	32	33	34	35	36	37	38	39	40
Analysis, wt %:										
MgO.....	14.6	17.7	NA	17.5	10.0	11.0	9.1	6.6	10.7	4.5
Al ₂ O ₃	11.8	7.2	NA	7.6	8.2	9.9	9.1	7.0	9.8	15.5
FeO.....	11.0	8.5	10.0	16.0	13.0	16.0	13.0	16.0	22.0	21.0
Fe ₂ O ₃	5.8	7.4	NA	1.9	6.2	4.5	7.6	4.9	0.0	9.2
Cr ₂ O ₃	54.6	53.6	NA	51.6	58.8	57.1	57.8	59.7	60.3	46.9
SiO ₂	.20	.28	NA	.49	.01	.18	.19	NA	.08	.70
P ₂ O ₅	.08	.10	NA	.11	.21	.10	.07	.04	.11	.08
TiO ₂	.44	.30	NA	.29	.24	.28	.29	.27	.31	.38
NiO.....	.09	.09	NA	.09	.04	.06	.07	.03	.05	.03
ZnO.....	.04	.05	NA	.05	.05	.05	.04	.05	.04	.14
d-spacing...Å..	2.5020	2.5045	2.5025	2.5040	2.5050	2.5065	2.5070	2.5100	2.5065	2.5030
Unit cell...Å..	8.298	8.306	8.300	8.305	8.308	8.313	8.315	8.325	8.313	8.302
Sample No.....	41	42	43	44	45	46	47	48	49	50
Analysis, wt %:										
MgO.....	8.7	NA	NA	NA	15.3	13.2	NA	11.2	10.3	NA
Al ₂ O ₃	10.3	NA	NA	NA	11.8	17.6	NA	11.3	18.1	NA
FeO.....	19.0	NA	NA	NA	13.0	13.0	15.0	17.0	18.0	20.0
Fe ₂ O ₃	9.6	NA	NA	NA	5.4	7.2	NA	8.2	14.0	NA
Cr ₂ O ₃	49.2	NA	NA	NA	51.7	46.7	NA	48.2	38.1	NA
SiO ₂	.46	NA	NA	NA	.47	.15	NA	.08	.21	NA
P ₂ O ₅	.11	NA	NA	NA	.13	.12	NA	.14	.14	NA
TiO ₂	.36	NA	NA	NA	.27	.25	NA	.23	.75	NA
NiO.....	.10	NA	NA	NA	.09	.08	NA	.04	.09	NA
ZnO.....	.09	NA	NA	NA	.05	.08	NA	.10	.23	NA
d-spacing...Å..	2.5120	2.5155	2.5255	2.5260	2.4995	2.4915	2.5090	2.5045	2.4985	2.5005
Unit cell...Å..	8.331	8.343	8.375	8.380	8.290	8.263	8.321	8.306	8.286	8.293
Sample No.....	51	52								
Analysis, wt %:										
MgO.....	15.7	6.2								
Al ₂ O ₃	9.4	8.3								
FeO.....	11.0	22.0								
Fe ₂ O ₃	8.7	12.8								
Cr ₂ O ₃	49.4	48.2								
SiO ₂	.66	.15								
P ₂ O ₅	.08	.15								
TiO ₂	.22	.14								
NiO.....	.09	.03								
ZnO.....	.06	.38								
d-spacing...Å..	2.5075	2.5095								
Unit cell...Å..	8.316	8.323								

NA Not analyzed.

¹All analyses by X-ray fluorescence except FeO which was done by Reno Research Center using wet chemical methods. X-ray fluorescence and X-ray diffraction results by Alaska Field Operations Center, Juneau, AK.

APPENDIX B.--NUMBER OF CATIONS PER 32 OXYGENS¹

Sample No.....	2	3	8	13	14	15	16	17	18	19
Cation:										
Fe ²⁺	3.70	3.80	4.44	2.57	3.12	3.42	3.65	3.59	3.24	3.96
Mg ²⁺	4.30	4.20	3.56	5.43	4.88	4.58	4.35	4.41	4.76	4.04
Fe ³⁺	0.49	1.34	2.55	1.39	1.26	1.03	2.37	0.76	1.87	2.62
Cr ³⁺	12.00	7.19	5.13	10.30	11.07	8.35	4.79	12.34	4.99	9.00
Al ³⁺	3.51	7.47	8.32	4.31	3.67	6.62	8.84	2.90	9.14	4.37
RO/R ₂ O ₃ ²	0.88	0.78	0.80	0.73	1.00	0.90	0.92	1.15	0.69	0.78
Molecular ratio: ³										
Fe ²⁺ /Fe ²⁺ +Mg ²⁺	0.46	0.47	0.55	0.32	0.39	0.43	0.45	0.45	0.41	0.49
Cr ³⁺ /Cr ³⁺ +Al ³⁺	0.77	0.49	0.38	0.71	0.75	0.56	0.35	0.81	0.35	0.67
Sample No.....	20	21	22	23	25	26	27	28	31	32
Cation:										
Fe ²⁺	2.89	1.34	1.98	2.59	2.21	4.13	1.42	2.94	2.38	1.70
Mg ²⁺	5.11	6.65	6.02	5.41	5.79	3.87	6.58	5.06	5.62	6.30
Fe ³⁺	1.80	6.65	1.82	1.49	1.26	2.76	2.26	0.80	1.14	1.58
Cr ³⁺	10.24	3.67	11.86	9.23	11.68	6.87	10.91	13.95	11.24	12.01
Al ³⁺	3.96	5.68	2.32	5.27	3.06	6.37	2.83	1.25	3.62	2.41
RO/R ₂ O ₃ ²	0.98	1.48	0.72	1.21	0.89	0.78	0.66	1.17	1.01	1.19
Molecular ratio: ³										
Fe ²⁺ /Fe ²⁺ +Mg ²⁺	0.36	0.17	0.25	0.32	0.27	0.52	0.17	0.37	0.30	0.21
Cr ³⁺ /Cr ³⁺ +Al ³⁺	0.72	0.82	0.84	0.64	0.79	0.52	0.79	0.92	0.76	0.83
Sample No.....	34	35	36	37	38	39	40	41	45	46
Cation:										
Fe ²⁺	2.71	3.37	3.60	3.56	4.61	4.29	5.79	4.41	2.58	2.85
Mg ²⁺	5.29	4.63	4.40	4.44	3.39	3.71	2.21	3.59	5.42	5.15
Fe ³⁺	0.45	1.23	0.90	1.47	1.00	0.00	1.78	1.98	1.10	1.37
Cr ³⁺	12.75	12.23	12.00	11.76	12.77	12.88	9.53	10.68	11.11	9.36
Al ³⁺	2.80	2.54	3.10	2.76	2.23	3.12	4.69	3.33	3.78	5.26
RO/R ₂ O ₃ ²	1.54	0.85	0.99	0.77	0.79	1.16	0.78	0.99	1.14	0.97
Molecular ratio: ³										
Fe ²⁺ /Fe ²⁺ +Mg ²⁺	0.34	0.42	0.45	0.33	0.58	0.53	0.72	0.55	0.32	0.35
Cr ³⁺ /Cr ³⁺ +Al ³⁺	0.82	0.83	0.79	0.81	0.85	0.81	0.67	0.76	0.75	0.64
Sample No.....	48	49	51	52						
Cation:										
Fe ²⁺	3.68	3.96	2.26	5.33						
Mg ²⁺	4.32	4.04	5.74	2.67						
Fe ³⁺	1.71	2.72	1.85	2.68						
Cr ³⁺	10.58	7.77	11.02	10.50						
Al ³⁺	3.70	5.51	3.13	2.72						
RO/R ₂ O ₃ ²	1.07	0.98	1.15	0.96						
Molecular ratio: ³										
Fe ²⁺ /Fe ²⁺ +Mg ²⁺	0.46	0.50	0.28	0.66						
Cr ³⁺ /Cr ³⁺ +Al ³⁺	0.74	0.58	0.78	0.80						

¹Cation proportion calculations are based on Stevens (12). Unit cell contains 8 R²⁺ cations, 16 R³⁺ cations, and 32 oxygen atoms.

²Ratio based on molecular proportions calculated from data in appendix A.

³Molecular ratios are calculated from data in appendix A and are plotted on figure 5. Fe²⁺/Fe²⁺ + Mg²⁺ represent values along the x-axis, and Cr³⁺/Cr³⁺ + Al³⁺ represent values along the y-axis.

APPENDIX C.--MINERAL TERMS AND SAMPLE KEY

Sample	Field	Locality	Mineral terms
LOCALITIES IN INTERIOR ALASKA			
1.....	WB20438.....	Avan Hills.....	ND.
2.....	WB16537.....	...do.....	Magnesiochromite, aluminian.
3.....	WB16538.....	...do.....	Spinel, chromian.
4.....	WB20435.....	...do.....	ND.
5.....	WB20436.....	...do.....	ND.
6.....	WB20437.....	...do.....	ND.
7.....	WB16539.....	...do.....	ND.
8.....	WB16540.....	...do.....	Hercynite, chromian.
9.....	WB16541.....	...do.....	ND.
10.....	WB20825.....	...do.....	ND.
11.....	WB20826.....	...do.....	ND.
12.....	WB20827.....	...do.....	ND.
13.....	WB16768.....	...do.....	Magnesiochromite, aluminian.
14.....	PT16641.....	Caribou Mountain.....	Do.
15.....	PT16637.....	...do.....	Do.
16.....	PB15787.....	...do.....	Spinel, chromian.
17.....	PT16635.....	Kanutu River.....	Magnesiochromite, ferroan.
18.....	PT16638.....	...do.....	Spinel, chromian.
19.....	PT16639.....	...do.....	Magnesiochromite, aluminian.
20.....	PT16636.....	...do.....	Do.
21.....	KW20780.....	Yuki River.....	Magnesiochromite, ferrian.
22.....	KW20782.....	...do.....	Magnesiochromite, aluminian.
23.....	KW20779.....	...do.....	Do.
24.....	KW19476.....	Mount Hurst.....	ND.
25.....	KW19477.....	...do.....	Magnesiochromite, aluminian.
26.....	KW19868.....	...do.....	Chromite, aluminian.
27.....	KW19881.....	...do.....	Magnesiochromite, aluminian.
LOCALITIES ALONG EXTENSION OF CHUGACH MOUNTAINS			
28.....	CM20261.....	Grant Lagoon.....	Magnesiochromite, ferroan.
29.....	CM20268.....	Halibut Bay.....	ND.
30.....	CM19277.....	...do.....	ND.
31.....	CM18624.....	...do.....	Magnesiochromite, aluminian.
32.....	CM19649.....	...do.....	Do.
33.....	CM11168.....	...do.....	ND.
34.....	CM19641.....	Miners Bay.....	Magnesiochromite, ferroan.
35.....	CM17679.....	Claim Point.....	Do.
36.....	CM19680.....	...do.....	Do.
37.....	CM17675.....	Red Mtd-Kenai.....	Do.
38.....	CM17670.....	...do.....	Chromite, magnesian.
39.....	CM17670.....	...do.....	Do.
40.....	CM19312.....	Eklutna.....	Do.
41.....	CM19322.....	Wolverine Complex.....	Do.
42.....	CM19326.....	...do.....	ND.
43.....	CM19371.....	...do.....	ND.
44.....	CM19373.....	...do.....	ND.
45.....	CM20488.....	Tonsina-Bernard.....	Magnesiochromite, aluminian.
46.....	CM20497.....	...do.....	Do.
47.....	CM18678.....	...do.....	ND.
48.....	CM20467.....	Sheep Hill.....	Magnesiochromite, ferroan.
49.....	CM20466.....	...do.....	Do.
50.....	CM20443.....	Dust Mountain.....	ND.
51.....	1S153.....	Red Bluff Bay.....	Magnesiochromite, aluminian.
52.....	2S430.....	...do.....	Do.

ND Insufficient data to designate mineral term (no chemical data).

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